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# Neutron source capability assessment for cumulative fission yields measurements

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# Neutron source capability assessment for cumulative fission yields measurements

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## Motivation

A recent analysis of high-quality cumulative fission yields data for Pu-239 published in the peer-reviewed literature showed that the quoted experimental uncertainties do not allow a clear statement on how the fission yields vary as a function of energy. [Prussin2009] To make such a statement requires a set of experiments with well "controlled" and understood sources of experimental errors to reduce uncertainties as low as possible, ideally in the 1 to 2% range.
The Inter Laboratory Working Group (ILWOG) determined that Directed Stockpile Work (DSW) would benefit from an experimental program with the stated goal to reduce the measurement uncertainties significantly in order to make a definitive statement of the relationship of energy dependence to the cumulative fission yields. Following recent discussions between Lawrence Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL), there is a renewed interest in developing a concerted experimental program to measure fission yields in a neutron energy range from thermal energy (0.025 eV) to 14 MeV with an emphasis on discrete energies from 0.5 to 4 MeV. Ideally, fission yields would be measured at single energies, however, in practice there are only "quasi-monoenergetic" neutrons sources of finite width. This report outlines a capability assessment as of June 2011 of available neutron sources that could be used as part of a concerted experimental program to measure cumulative fission yields. In a framework of international collaborations, capabilities available in the United States, at the Atomic Weapons Establishment (AWE) in the United Kingdom and at the Commissariat à l'Énergie Atomique (CEA) in France are listed.

## Methods

The neutron sources described in this report were identified in two ways. Two internet databases, the Research Reactor database published by IAEA and the Research and Test Facility database published by NEA/OECD were mined. [IAEA2010][OECD2009] Search parameters ranged from country, operational status, beam types to possibility of experiments, applications and others. Simultaneously, experimentalists were asked for suggestions. Interestingly, there was a very good overlap between their recommendations and what was found in the databases.

Selection of the facilities to contact for further information and potential inclusion in this compilation was done based on the internet search and experimentalist's recommendations. Commercial reactors, reactor facilities without a webpage, or those facilities that could be identified as focused on teaching and training were not contacted.

Points-of-contact were identified for each neutron source via the web or through experimentalists that had some knowledge of the facility. They were contacted by email and were asked to give information according to the set of criteria described in the first column of table 1 to 5.

Several neutron source facilities were initially contacted but were not included in the analysis for the following reasons:

- No answer was received.
- The facilities are specialized fission or monoenergetic sources dedicated to specific research topics, such as material sciences research at the Oakridge Neutron Sciences Center, which operates the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR).
- The facilities indicated that they were dedicated to training and education.

While striving for completeness, it is entirely possible that some sources were not included which should have been. Please feel free to contact the authors with information on those facilities for inclusion.

## Capabilities

The results are presented in table 1 to 5. Table 1 and 2 show US monoenegetic and fission neutron sources. Some US white neutron sources are given in Table 3. They were included for the sake of completeness. Although the type of experiments currently envisioned will rely on well-characterized fission or monoenergetic sources, it is entirely possible that experiments using white sources will be planned later on.

Two potential neutron sources have been identified by our AWE point of contact. The Accelerator Steady Pulse (ASP) at AWE Aldermaston and the 3.5 megaelectron Volt (MeV) Van den Graaff accelerator at the National Physical Laboratory. At this time, it is unclear if the necessary authorizations to conduct experiments with special nuclear material are in place. In case they are not, the time required to obtain such authorizations is not known.

Several CEA neutron sources have been identified. The High Flux Reactor at the Institut Laue-Langevin (HFR/ILL) in Grenoble delivers the highest thermal flux of all facilities. Orphee is a reactor with at least one user-based beam line. Two fast flux critical assemblies Caliban and Prospero may be available at Valduc/DAM. Finally, a 4.0 MeV Van den Graaff accelerator is available at Bruyère-le-Châtel, and can deliver neutron beams with energy from 0.5 to 4 MeV as well as 14 MeV depending on the ion beam/target configuration. All facilities appear to have the necessary authorizations to conduct experiments with special nuclear material.

AWE and CEA capabilities are described in Table 4.

During this assessment, it became clear that there is a fourth category of sources, those that are not currently operational but could be available. These include four “classic” fast critical assemblies (Godiva, Comet, Flat Top and Planet) which were recently moved to a dedicated facility at the Nevada Nuclear Security Site (NNSS). These assemblies, previously located at Los Alamos National Laboratory, were well characterized and used in criticality and reaction ratio benchmark experiments for decades.[NEA2005] The Dense Plasma Focus (DPF) fusion source at NNSS could be modified specifically for this experimental program and the 7 MeV accelerator that was used for the cargo neutron interrogation project at LLNL could be restarted. The 2 MV tandem accelerator at the TAMU Nuclear Science Center would need a license to produce neutrons. These capabilities are summarized in Table 5.

## Conclusion

There is a need to develop an experimental program that will reduce the measurement uncertainties significantly in order to make a definitive statement of the relationship of energy dependence to the cumulative fission yields.

Fission and monoenergetic neutron sources are available that could support these fission yield experiments in the US, as well as at AWE and CEA.

Considerations that will impact the final choice of experimental venues are:

- Availability during the timeframe of interest
- Ability to accommodate special nuclear materials
- Cost
- Availability of counting facilities
- Expected experimental uncertainties

### References

[Prussin2009] Prussin S. et al. Review of the Status of Cumulative Fission Yields from 239Pu(n,f) of Interest to Nuclear Forensics ( LLNL-TR-458777) 2009.

[IAEA2010] http://www-naweb.iaea.org/napc/physics/research_reactors/database/RR Data Base/datasets/foreword_home.html accessed July 2010
http://www.iaea.org/worldatom/rrdb/

[OECD2009] Research and test facilities required in nuclear sciences and technology OECD/NEA 2009 ISBN 978-92-64-99070-8 / NEA No. 6293.
www.new.fr/rtfdb accessed July 2010.

[NEA2005] NEA Nuclear Science Committee 2005, "International Handbook of Evaluated Criticality Safety Benchmark Experiments" OECD NEA/NSC/DOC(95)03 September 2005 Edition.

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Table 1. Fission sources

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **website** | http://mnrc.ucdavis.edu/about.html | http://web.mit.edu/nrl/www/ | | | | http://www.murr.missouri.edu/ | http://neutrons.ornl.gov/facilities/HFIR/ |
| **Facility name** | **McClellan Nuclear Research Center** | **MIT Reactor Lab** | | | | **MUUR** | **High Flux isotope reactor (HFIR)** |
| **Facility location** | Sacramento, CA | MIT, Cambridge, MA | | | | Washington Univ, Columbia, MI | Neutron Sciences<br>Oakridge National Lab. |
| **Facility status** | operational | operational | | | | operational | operational |
| **Facility contact information** | Moe Boussoufi<br>Experiment Coordinator/Radioisotope Manager<br>tel: (916) 614-6200<br>toll free: (888) 377-7957<br>fax: (916) 614-6250<br><br>mboussoufi@ucdavis.edu<br><br>general email:<br>mnrc@ucdavis.edu | Tom Newton Associate Director, Reactor Engineering<br>tel: (617) 253-4211<br><br>tnewton@mit.edu | | | | MUUR Director (thermal beams)@missouri.edu<br>tel: (916) 614-6200<br>customer servces: 573 882-4211<br>murrinquiries@missouri.edu<br><br>Dr. J. David Robertson<br>Associate Director, Research and Education<br>tel: (573) 882-5346 (MURR)<br>RobertsonJo@missouri.edu<br><br>Dr. John Brockman<br>Assistant Res. Prof.<br>University of Missouri Res. Reactor Center<br>Research Park Drive<br>Columbia, MO 65211<br>tel: (573) 884-8095 (MURR)<br>brockmanJD@missouri.edu | Chris Bryan<br>Experiments and Isotope production<br>Neutron Sciences<br>Oak Ridge National Laboratory<br><br>tel: (865) 241-4336<br><br>bryancd@ornl.gov |
| **Beam source** | Nuclear reactor | Nuclear reactor: 4 beam lines | | | | Nuclear reactor | High Flux Nuclear Reactor |
| **Beam line ID** | Bay#4 | 4DH1 | 4DH3 | 4DH4 | Medical beam | | Multiple irradiation locations and 4 beams |
| **description** | | Student chopper beam | Prompt gamma diffracted beam | Diffractometer beam | Thermal BNCT beam | Most thermal neutron beam in new small animal BNCT testing facility | Neutron scattering experiments, Neutron Activation Analysis (NAA), isotope production |
| **Available beam intensity (1x10? neutrons/cm sq/sec)** | 3E+05 n/cm2/s @ 1 MW | | | | | | 3E+15 n/cm2/s @ 85 MW |
| | 4.5E+05 n/cm$^2$/s (thermal flux) | | ~1E+07 n/cm$^2$/s | White beam of 1 inch diameter: 1E+07 neutrons/cm$^2$/s and Monochromatic beam 2x3 inch, 14.7 MeV: 3E+06 neutrons/cm$^2$/s | ~1E+10 n/cm$^2$/s | Thermal flux: 8.9E+08 n/cm$^2$/s | Thermal flux:<br>4.3E+14 – 2.5E+15 n/cm$^2$/s depending on in-vessel location<br>3 thermal and 1 cold beam tubes<br>(to 10 neutron scattering instruments) |

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| **Beam energy level(s) (?mev neutrons)** | Thermal flux has maxwellian spectrum (< 1eV) Fast flux(>1 MeV) has half the value of the thermal | Thermal spectrum at about 50 C, with epithermal component at about 1 eV | | Thermal beam, (calculated thermal flux energy distribution available). Fast neutron flux unknown | Thermal beam | Cd ratio of 129 | In-vessel thermal beam, >0.111MeV , >0.821 MeV<br><br>Pneumatic tubes:<br>PT-1: Thermal Neutron Flux: 4E+14 n $cm^{-2}$ $s^{-1}$ Thermal/epithermal ratio:40<br>PT-2: Thermal Neutron Flux: 4E+13 n $cm^{-2}$ $s^{-1}$ Thermal/epithermal ratio: 200 |
| **How does the facility characterize the beam intensity and energy – detectors, standards, calibration** | Gold foils and Cd-covered gold foils | Beam energy determined by time of flight spectroscopy | Gold foils | Gold foils for absolute flux. Also He3 and scintillator detectors. | Gold foils, graphite and tissue equivalent proportional counters | Thermal, epithermal and fast flux foils were irradiated to check the models. The a priori neutron spectrum was calculated using DORT. Based on the measured activities of the foils and the corrected cross sections of the flux foils a least squares algorithm was used to calculate an adjusted detailed spectrum. Summary table available. The thermal beam was constructed using silicon crystal and bismuth crystal filters and as a result there is a significant fraction of epithermal neutrons in the range of 214 eV o 297,000 eV (3.2% of total flux). | |
| **How well characterized is the beam** | | Energy is well characterized, intensity not well characterized | Full spectrum not available, but could be done by using foils. Gammas can be filtered by Bi filter, but gammas were not measured. | Well characterized for BNCT irradiations | | | Well characterized in core flux |
| **What is beam spot size?** | 1.25 in x 1.25 in aperture with an L/D ratio of 270 | Approximately 0.5 x 10 mm, final collimation could be changed to increase spot size to about 2 x 20 mm | ~2 cm diameter | Variable, up to 2x3 inch. | Variable, up to 15 cm diameter | Neutron flux is homogenous (<10% variation) across the beams 6-in diameter with the neutron flux decreasing sharply outside the 6-in diameter beam | H1B- H3B: 2.75-in x 5.5-in. rectangular aperture.<br>H2B: 6-in tall x 10-in wide + additional collimation<br>H4B: collimator provides 3 rectangular apertures with outboard dim:1.61 in x 4.33 in; 2.17 in x 3.65 |

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| | | | | | | | in; 1.78 in x 4.33 in. |
| **Evaluation of beam anisotropy – how isotropic is the beam that the target will see?** | Quasi parallel beam, with a L/D ratio of 270 | | FWHM from monochrometer is 2.4 degrees | The beam is pretty isotropic, maximum beam divergence is about 1 degree. The divergence can be reduced by collimators. | d | Very collimated | |
| **Evaluation of room return.** | N/A | N/A | N/A | N/A | Insignificant (floor is 10 feet from beam entrance on ceiling) | Did not observed a significant "bounceback" at the irradiation position in the thermal beam. The entire irradiation chamber is covered with a boron containing rubber or silicon to cut down on room return. The shielding was purchased from Shieldwerx (formally thermal, formally reactor experiments). We use both the SWX-227A flexi panel (9% boron) and the SWX-238 Flexi boron (25% boron) in different areas of the chamber. | N/A |
| **Is there a standard simulation input for the facility? (input deck for MCNP)** | Yes, MCNP run | Input deck for MCNP or other Monte Carlo code | | It is possible to do MCNP calculations, augmented by ray-tracing | MCNP | Beam modeled using the DORT code with a modified 59 group cross section table (expanded from the 47 energy group Bugle-80 library to add detail the thermal section.) The DORT code was used to construct a source plane for a detailed MCNP5 model located just before the irradiation position. thermal, epithermal and fast flux foils were irradiated to check the models | MCNP ORNL/TM-2004/251 |
| **Facility sample analysis/characterization capability – what equipment/ detectors, standards, calibration** | Four High purity Germanium detectors | High purity Germanium detector | High purity Germanium detector | Au foils, He3 and scintillator detectors, ASTM imaging standards | In beam BF3 detectors | | Neutron Activation Analysis with two pneumatic shuttle system (Be reflector) Hydraulic shuttle irradiation facility (high flux core) |

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| **What target samples are allowed under existing Authorization Basis - material type, purity, mass, isotopics** | There is a limit on highly enriched uranium, so that the max U-235 content < 2gm. There is a limit on the amount of sample if it produces strontium and/or iodine in excess of our tech specs. The max amount of explosives allowed is 3 lbs TNT equivalent | | | | | | Pneumatic system sample container: 1 $cm^3$, 1.448cm diameter Hydraulix shuttle: sample 2 3/16-in long x0.255-in diameter<br><br>In core variable size depending on location |
| **What are target size restrictions - (area, volume)** | Target size should be sufficiently thin to allow passage of neutrons and have an area < 1 $ft^2$ if close to fast shutter and < 2.25 $ft^2$ if at farthest distance. | About 2-ft x 2-ft can be easily accommodated. | Current sample size is restricted to 8-in by 8-in, but can be increased if necessary. | A target much larger than, 2x2 meters might be difficult to accommodate. For very small targets, we have goniometers and other precise motion devices. | Large space, pretty much unlimited size. Beam is vertical, emanating from the ceiling, so samples must be raised. | | In-core size sample limited by available volume / neutron poison |
| **Are there any target geometry restrictions?** | Beam shape is square and target must be thin in one direction | | | | | | |

Table 2. Monoenergetic sources

| | | |
|---|---|---|
| **website** | http://edwards1.phy.ohiou.edu/~oual | http://www.tunl.duke.edu/ |
| **Facility name** | **Edwards Accelerator Laboratory** | **TUNL - Triangle Universities Nuclear Laboratory** |
| **Facility location** | Ohio University, Athens, OH | Duke University, Durham, NC |
| **Facility status** | Operational | Operational |
| | Dr. David C. Ingram<br>Edwards Accelerator Laboratory, Rm106<br>Department of Physics and Astronomy<br>University Terrace, Ohio University<br>Athens, Ohio 45701-2979<br>tel: (740) 593-1705 (office)<br>tel: (740) 593 -986 (laboratory)<br>fax: (740) 593-1436<br><br>ingram@ohio.edu | Dr. Anton P. Tonchev<br>Department of Physics 410 TUNL<br>Duke University<br>Durham, NC<br>tel: (919) 660-2636 (office)<br>fax: (919) 660-2634 (fax)<br>tonchev@tunl.duke.edu<br><br>Dr. Henry R. Weller<br>tel: (919) 660-2633 (office)<br>fax: (919) 660-2634 (fax)<br>weller@tunl.duke.edu |
| **Beam source** | 4MeV tandem accelerator<br>d,d d,t, p,t, are often used but many other reactions are possible<br>Target T(solid, gas); D(solid, gas);<br>3He (gas); 15N(gas) –<br>Solid target: Li,Be,B,C,Al - some are single isotope. | Tandem accelerator, 2H(D,n)3He and 3H(p,n)3He reactions. |
| **Available beam intensity (1x10? neutrons/cm sq/sec)** | Depends on the reaction -<br>Up to 10E+13 neutrons; 20 cm from source 10E+7 neutrons/cm$^2$/s<br>6 beam lines (one is 30m TOF tunnel, well shielded, with beam swinger) see email below | Neutron flux = 0.5 n/cm®/s from 2 microA beam current on 7 atm (~103 PSI) pressurized gas cell.<br>This neutron beam is not collimated, except for "Shielded source area" where the beam is well collimated through a shielding wall.<br>Typically run with 200 ns between bursts, but this can be varied up to a microsecond.<br>Sample distance to the end of the gas cell = 4.5 cm. |
| **Beam energy level(s) (?mev neutrons)** | Neutrons from 0.5 - 20 MeV can be produced depending on the reaction used | First reaction: monoenergetic n-beams from 4 to 18 MeV.<br>Second reaction: neutrons from 1.5 to 7 MeV. |
| **How does the facility characterize the beam intensity and energy – detectors, standards, calibration** | Charge on target known within 10%. Apertured system with an aperture that can be varied from a few to 20 cm in diameter- Reference article on neutron energy measurements available. The terminal voltage was calibrated using well known nuclear reactions and the calibration transferred to an NMR system used in combination with a mass analysis magnet. Beam currents are measured in suppressed mode or in faraday cups depending on the design of the experimental system. The current is integrated with a beam current integrator that is occasionally checked with the Keithley constant current source. | We rely on the activation monitors from Au, Al, and Ni foils. You can use neutron detector in the beam and simulate the detector efficiency with MCNP to get the absolute neutron flux. |
| **How well characterized is the beam** | Very well, but it depends on what it means. Pulsing and bunching (timing information, precise neutron energy characteristics) | Monitoring of the time fluctuation of the n-beam using neutron detectors. |
| **What is beam spot size?** | Usually less than 3 mm diameter, one beam line has as scanner for irradiation of 1 cm$^2$ samples. | Collimated neutron beam is used for in-beam measurements. However in this case the neutron flux on target position (2.5 m from the gas cell ) is 2-E+04 n/cm$^2$/s with average beam current (2H beam) of 1.5 microA. The collimated neutron beam has a diameter of 4.5 cm. |

| | | |
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| **Evaluation of beam anisotropy – how isotropic is the beam that the target will see?** | It is focused but is probably a gaussian | The beam is rather isotropic according to measurements with films. |
| **Evaluation of room return.** | This can be done, but is not usually done. No known evaluation of room return | Does not know if measurements were done. With neutron detectors like Li-glass, can measure down to 50 keV.<br>Maybe can use different monitor foils (In, Cd, V, ect.) to extract the very low energy component of the thermal part of the n-spectrum. |
| **Is there a standard simulation input for the facility? (input deck for MCNP)** | James Hall @ LLNL developed a COG input deck | no standard input deck but do run MCNPX |
| **Facility sample analysis/characterization capability – what equipment/ detectors, standards, calibration** | RBS, ERS, XPS, SAM, NRA... Counting detectors: HpGe, BGO, NaI | Do have all type of HPGe detectors, neutron detectors, NaI, plastic, charge particle, He3- proportional chamber, etc.<br>Do have all common used gamma, neutron, and alpha callibrated sources.<br>Not equipped for radiochemical or mass separation analysis.<br>Neutron time of flight setup: an open geometry which uses "shadow "bars to shield the neutron detectors from source neutrons |
| **What target samples are allowed under existing Authorization Basis - material type, purity, mass, isotopics** | Existing license for radioactive target Pu-239 100 microCi sealed source (encapsulated Pu-Be) | All stable targets are allowed. If the target is an actinide target, then we need a license permission to run. |
| **What are target size restrictions - (area, volume)** | Depends on the beamline and on whether the target is in vacuum or not. | For stable targets there are not size restriction. For actinides, the limit is the University license regulation.4 grams of 239Pu (maxed during Micah Jonhson's experiment) |
| **Are there any target geometry restrictions?** | See previous question. | No |

Table 3. White neutron sources

| | | |
|---|---|---|
| **website** | http://lansce.lanl.gov/ | |
| **Facility name** | **LANSCE** | **RPI** |
| **Facility location** | LANL, NM | Troy, NY |
| **Facility status** | Operational | Operational |
| **Facility contact information** | | Yaron Danon<br>Professor, Director Gaerttner LINAC Laboratory<br>Dep.of Mechanical, Aerospace and Nuclear Engineering<br>NES Bldg. 1-9<br>Rensselaer Polytechnic Institute<br>Troy, NY 12180<br>tel: (518) 276-4008<br>Fax: (518) 276-4832<br><br>danony@rpi.edu |
| **Beam source** | 2 spallation "white" neutron sources<br>- Manuel J. Lujan Neutron Scattering Center (thermal beams)<br>- Weapon Neutron Research facility provides "bare-target" or MeV-spectra neutrons, each on a variety of different flight paths | High energy LINAC generate "white" neutron source |
| **Available beam intensity (1x10? neutrons/cm sq/sec)** | High flux<br>WNR: for 15 degree flight path, neutron flux at 1 MeV ~ 0.1 N/MeV/Sr/proton, which corresponds to 1E+6 neutrons/MeV/cm2/second at 10 m and 1.6 microA (Typical running conditions). | High flux |
| **Beam energy level(s) (?mev neutrons)** | | |
| **How does the facility characterize the beam intensity and energy – detectors, standards, calibration** | | |
| **How well characterized is the beam** | | |
| **What is beam spot size?** | | |
| **Evaluation of beam anisotropy – how isotropic is the beam that the target will see?** | | |
| **Evaluation of room return.** | | |
| **Is there a standard simulation input for the facility? (input deck for MCNP)** | MCNP decks for some of the flight paths | |
| **Facility sample analysis/characterization capability – what equipment/ detectors, standards, calibration** | | |
| **What target samples are allowed under existing Authorization Basis - material type, purity, mass, isotopics** | Can handle actinide samples for most needs - there are authorization basis limits and "material at risk" considerations. | |
| **What are target size restrictions - (area, volume)** | | |
| **Are there any target geometry restrictions?** | | |

Table 4. AWE and CEA capabilities

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Website** | http://www.awe.co.uk/ | http://www.npl.co.uk/about/ | http://nucleaire-saclay.cea.fr/en/Phocea/Vie_des_labos/Ast/ast_theme.php?id_ast=52 | | http://www.ill.eu/ | | | |
| **Facility name** | **Accelerator Steady Pulsed (ASP)** | **NPL Monoenergetic Neutron Facility** | **ORPHEE** | | **High flux reactor, ILL** | **PROSPERO** | **CALIBAN** | **4MV Van De Graaf** |
| **Facility location** | AWE Aldermaston | National Physical Laboratory | Laboratoire Leon Brillouin/Saclay | | ILL/ Genoble | CEA/DAM in Valduc | CEA/DAM in Valduc | CEA/DAM/Bruyeres-le-Chatel |
| **Facility status** | Operational | Operational | Operational | | Operational | Operational | Operational | Operational |
| **Facility contact information** | Shaun Hughes<br>AWE<br>Aldermaston,<br>Reading,<br>Berkshire, RG7 4PR<br>United Kingdom<br>tel: +44 11 8982-4122<br><br>shaun.hughes@awe.co.uk | Nigel Hawkes<br>NPL<br>Hampton Road,<br>Teddington,<br>Middlesex, TW11 0LW<br>United Kingdom<br>tel: +44 20 8943 -7064<br><br>Nigel.hawkes@npl.co.uk | Alain Menelle, Deputy Director<br>Laboratoire Léon Brillouin<br>(CEA-CNRS)<br>CEA Saclay<br>91191 Gif-sur-Yvette Cedex<br>France<br>tel: +33 1 69-08-96-99<br>+33 1 69-08-90-20<br>fax:+33 1 69-08-82-61<br><br>alain.menelle@cea.fr | | Oliver Zimmer,<br>Nuclear Physics Gp, Manager<br>ILL<br>BP 156<br>6, rue Jules Horowitz<br>38042 Grenoble Cedex 9<br>France<br>tel: +33 4 76-20-74-29<br>zimmer@ill.fr<br><br>Ullie Koester<br>tel: +33 4 76-20-71-54<br>koester@ill.fr | Thierry Granier<br>Commissariat a l'Energie Atomique<br>(CEA)<br>Centre DAM - Ile de France<br>Service de Physique Nucleaire<br>Bruyeres-le-Chatel<br>91297 Arpajon Cedex<br>France<br>+33 1 69-26-57-86<br>+33 1 69-26-70-63 (fax)<br><br>thierry.granier@cea.fr | | Jean-Gabriel MARMOUGET<br>Laboratoire des Accélérateurs Electrostatiques<br>CEA Bruyeres-le-Chatel<br>91297 Arpajon Cedex<br>France<br>+33 1 69-26-57-86<br>+33 1 69-26-70-63 (fax)<br><br>jean-gabriel.marmouget@cea.fr |
| **Beam source** | Atomic or Molecular Deuterons (D+T and D+D) | Neutrons produced by protons or deuterons beams from a 3.5MV Van de Graaff accelerator onto a thin neutron producing target at the centre of the experimental area. | Nuclear reactor<br><br>Two possible beamlines<br><br>Beam port G43 | Beam port 3T1 | Nuclear reactor (beamline: PF1B) | Fast critical assembly | Fast critical assembly | 4 MV Van de Graaf<br>Target 1H, 2H, 3He, 4He;<br>Energy 1H 1.3 to 4 MeV, 2H 0.5 to 4 MeV |
| **Available beam intensity (1x10? neutrons/cm sq/sec)** | 2.0E+10 n/cm$^2$/s | Maximum neutron intensity depends on production reaction. For example, ~1.6E+3 m/cm$^2$/s at 1 meter from target at 565 keV, and 6E+2 n/cm$^2$/s at same distance at 5MeV | 5.0E+5 n/cm$^2$/s | 1.66E+7 n/cm$^2$/s on 20*60 mm$^2$ | Capture flux up to 2E+10 n/cm$^2$/s | | | [1H and H2 beam, Neutron fluence for all targets > 1.E+7n/s/sr @ 6 microA]<br>0.03<En<0.7 ~3.7E+7 n/s/sr @ 6microA<br>0.7<En<3.0 ~8.5E+7<br>4.0< En<7.0 ~5.0E+7<br>15<En>20.7 ~1.7E+7 |

| | | | | | | | | |
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| **Beam energy level(s) (?mev neutrons)** | d+d = 3MeV;<br>d+t = 14MeV | Monoenergetic neutron fields covering a wide range of energies between 50 keV and 17MeV. | 0.235 < wavelength□ < 0.6 nm | A mixture of 50% at 2.36 A, 50% at 1.18 A | Cold neutrons with 5.4 MeV average energy. | Fast fission spectrum Mean neutron energy is on the order of 1.4 MeV or 0.7 MeV depending on irradiation positions | Fast fission spectrum Mean neutron energy is of order of 1.4 MeV or 0.7 MeV depending on irradiation positions | 7Li(p,n) 0.03<En<0.7 ~3.7E+7 n/s/sr @ 6microA<br>T(p,n) 0.7<En<3.0 ~8.5E+7<br>D(d,n) 4.0< En<7.0 ~5.0E+7<br>T(d,n) 15<En>20.7 ~1.7E+7<br>Neutrons from 500 keV to 7 MeV and at 14 MeV<br>Energy from 400 keV to 4 MeV<br>Continuous beam: courant < 200 A<br>for energy greater than 1.5 MeV, Pulsed beam |
| **How does the facility characterize the beam intensity and energy – detectors, standards, calibration** | U-238 fission detectors are used to determine neutron output; this type of detector is not responsive to thermal neutron interaction. For accurate calibration tasks, an associated alpha particle monitoring target assembly is used. This is more accurate as it relies on detection of the associated alpha particle with the d+t reaction. | Neutron energy from a given production target is determined by the energy of the charged particle beam, which is set by an analysing magnet and slits. The analysing magnet is itself calibrated using the observed thresholds of certain nuclear reactions, such as Li-7 (p,n). The intensity (fluence rate) is measured with a Long Counter that has been calibrated using radionuclide sources. The neutron output of the source is determined using the NPL manganese bath. | | Using gold foils/pallets and fission chamber | Intensity can be measured by Au foil activation or calibrated neutron detectors. Reference article available. | | | BF3 detector for low energy neutron;<br>NE213 liquid Scintillation detector |
| **How well characterized is the beam** | ASP produces a source of neutrons into 4 pi. Neutron energy vs. lab angle is well documented. | See above. Also the fluence rate at the position of the neutron detector or sample is typically known to 3 - 5 percent at 144 keV and 0.2 percent at 5 MeV. | | | See enclosed. | | | Neutron energy is well characterized in the domains listed above |

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| **What is beam spot size?** | See above. | Neutrons are emitted in 4pi, neutron fields rather than beams. | Width : 25 mm ; height 50 mm | | The full beam covers 20 cm (height) by 6 cm (width). It can be collimated to any smaller size. | | | Neutrons are emitted in 4pi. There is no collimation. |
| **Evaluation of beam anisotropy – how isotropic is the beam that the target will see?** | Neutron energy off accelerator target varies with angle. Neutrons emitted at 0 deg, i.e. directly in front of the target will have a higher energy than those emitted at an angle of say 97 deg. In this case: 0 deg will yield an energy of approximately 14.6 MeV, whilst at 97 deg the energy will be 14.0 MeV. | The neutron field covers the face of the detector or sample. If this represents a wide range of emission angles the variation in energy and intensity can be calculated using relativistic kinematics. | | quite large ~30% | See enclosed. | | | |
| **Evaluation of room return.** | No data is available for this as primary interest is fast neutrons. However the target cell has been designed as a low scatter environment. | The neutron producing target is at least 6 meters away from the floor, walls and ceiling of the experimental area; meaning that the room return is small. Nevertheless, it is routinely measured by placing a shadow cone between the production target and the detector to block all the neutrons coming directly from the target. | | | Depends on setup. Correct shielding by 6Li, 10B, etc. containing materials minimizes room return usually to acceptable level (<<1E-4). | | | room is large, room return is mostly from concrete floor |
| **Is there a standard simulation input for the facility? (input deck for MCMP)** | No | MCNP model of the main features of experimental area | | | The reactor spectra are simulated e.g. by MCNP and can serve as input for beamline simulations. | | | No |

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| **Facility sample analysis/characterization capability – what equipment/ detectors, standards, calibration** | ASP does not provide any sample analysis capability at present; users would be expected to provide any sample interrogation equipment as part of their trials plan. There will in the near future though be the capability to perform gamma spectroscopy measurements. | It would appear not. But the facility is only a short distance from the NPL Radioactivity Group who have a range of instruments that could potentially be utilised for such purposes. | 3He/Ancillary equipment<br>Be filter (77 K)<br>Furnace (20 - 1200°C)<br>Multidetector: only in diffraction mode (without analyzer)<br>Triple Axis Equipment Pool | | Sample should be characterized before sending to ILL. Usual gamma calibration sources are available. | | | Ge(Li) coaxial and planar detectors, sets of standards. |
| **What target samples are allowed under existing Authorization Basis - material type, purity, mass, isotopics** | Currently ASP is not permitted to hold or irradiate any explosive or fissile material. Samples required to be irradiated must be submitted with full details of expected isotopes produced and any additional radiological precautions which may be required. | Most of the detectors that they calibrate are inactive. However they do have authorisation for samples containing small quantities of fissile material; though it is unlikely they would be able to handle highly active unsealed samples. | | | All elements and isotopes are possible. General limit: 8mg 239Pu (as unspecified compound with 1 um granularity), other isotopes and compounds scale with radiotoxicity according to French radioprotection rules. Higher amounts are possible at beamlines in the reactor hall. They may also be possible at PF1B on request with special precautions (enclosure…) | | | Actinides are ok up to several grams. |
| **What are target size restrictions - (area, volume)** | No restrictions on sample size. However it is worth bearing in mind when producing trials plans that the uniformity of dose and irradiation time will be affected by the geometry of the sample / equipment under testing in relation to its position from the neutron producing target. | The open geometry of the experimental area means that a wide range of sample sizes and shapes cans be accommodated. | Space around target 2*2m$^2$ | Space around target 1*1m$^2$ | Only restricted by user-supplied experimental chamber. | | | No restriction |
| **Are there any target geometry restrictions?** | As above. | As above. | This type of irradiation is not done on this beam line, and will require a special safety analysis to define safety procedures. it could be quite difficult for Pu | | Only restricted by user-supplied experimental chamber. | No restriction | | |

Table 5. Future sources

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| **Website** | | | | | http://nsc.tamu.edu/ |
| **Facility name** | ***Critical Experiment Facility in the Device Assembly Facility*** | **Dense Plasma Focus (DPF) fusion neutron source** | ***ALEXIS*** | ***7 MEV accelerator*** | **TAMU Nuclear Science Center** |
| **Facility location** | *Nevada Nuclear Security Site, NV* | NSTEC facility, NV | *LLNL, CA* | *LLNL, CA* | Texas A&M, TX |
| **Facility status** | *Not operational, limited operation for testing (start expected end FY2011)* | Operational (need modification) | *Not operational* | *Not operational (in storage)*<br>*Information from cargo project* | Operational (need modifications, and currently no license to produce neutrons) |
| **Facility contact information** | *no point of contact* | Chris Hagen, NSTEC<br><br>hagenec@nv.doe.gov | *Larry Ahle, Jason Burke*<br><br>*tel: (925)422-4683*<br>*burke26@llnl.gov* | *Brian Rusnack*<br><br>*rusnak1@llnl.gov,*<br>*brusnak@nps.edu* | Dr. Dan Reece, Director<br>Nuclear Science Center<br>129 Zachry Engin. Bldg<br>3133 TAMU<br>College Station, TX 77843<br>tel: (979) 847-8946<br>fax: (979) 845-8946<br>w-reece@tamu.edu<br><br>Prof. Leslie Braby<br>(2 MeV tandem accelerator)<br>tel: (979) 862-1798<br>labraby@ne.tamu.edu |
| **Beam source** | *4 well characterized benchmark critical assemblies (Godiva, Comet, FlatTop, Planet)* | Yields ~5 x 1E12 neutrons per pulse<br>Pulse widths between 50 and 150 ns<br>Neutron production rates of up to 1020 neutrons per second,<br>Cycle time = 5 minutes. | *3 MeV Pelletron*<br>*Gas target & solid target* | *4 MeV, 425 MHz $D^{=}$ RFQ*<br>*current $I_D^+$ ~100microA average*<br>*$D_2$ target Gas cell*<br>*10 μm Mo foil (ΔE ≈ 730 keV)*<br>*$P_{D2}$ ≈ 1 atma (100 CFM flow rate)*<br>*L = 60 cm (stopping target)s* | 2 MV tandem that has been used in the past to make neutrons using DT, DD, and D-carbon reactions. Two ion sources - Duoplasmatron and RF source with rubidium charge exchange |
| **Anticipated beam intensity (1x10? neutrons/cm sq/sec)** | | The new DPF will yield 1E+14 neutrons per shot, at ten shots per day, 1E+15 neutrons per 6 hour day. | *20-40 keV $10^7$ n/cm$^2$/s*<br>*1.3-1.7 MeV >$10^7$ n/cm$^2$/s**<br>*6.0-6.5 MeV >$10^8$ n/cm$^2$/s*<br>*14.4-14.6 MeV >$10^7$ n/cm$^2$/s** | *$\Phi_n$ ≈ 7.43E+03 n/cm$^2$/μC (2.5 m)*<br>*$D_n$ ≈ 0.25 mrem/μC (2.5 m)* | Small fluence production. Dependent on target and shielding |
| **Beam energy level(s) (?mev neutrons)** | *Fission spectrum* | 2.45 MeV and 14 MeV | | *$E_n$ (max) ≈ 6.54 MeV @ 0°* | Dependent on target, potentially 0 to 15 MeV (hydrogen ion beams to 4 MeV) |
| **How does the facility characterize the beam intensity and energy – detectors, standards, calibration** | | | ** 5 Curie Tritium Target required for this flux* | | Precision long counter for intensity, neutron energy is obtained from ion energy and kinematics of the neutron production reaction. Ion energy is calibrated using the threshold energy of the Li(p,n) reaction |